Probabilistic Risk Assessment for the Sacramento-San Joaquin Delta Levee System

Prepared for

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Executive Summary

This proposal presents the objectives and scope of a project to conduct a probabilistic risk assessment for the Sacramento-San Joaquin Delta levee system. The purpose of the study is threefold:

1. Develop a probabilistic framework to evaluate the reliability of the levee system in the Delta and the probability of inundation.

2. In an initial application, demonstrate the methodology for one part (i.e., an island) of the levee system.

3. Develop an approach for measuring the benefit (i.e., risk reduction) of proposed levee modifications or repairs.

There are a number of special issues associated with an evaluation of the risk of levee failure and inundation that will considered. The first is the fact there are over 600 miles of levees that protect a large geographic region. Earth structures of this size pose special problems with respect to the availability of information (i.e., geotechnical data), assessing the likelihood of failure along a levee length, and modeling levee performance during events that are also spatially distributed such as earthquakes or floods. As a second matter, to assess the performance of a levee system for a specified service life, consideration must be given to factors that affect levee integrity, such as subsidence, deterioration, and time varying hazard potential (e.g., earthquake occurrences). A final issue concerns the development of a logic model that properly represents the combination of events that can con-tribute to levee failure and inundation.

The results of this study will include:

1. Documented probabilistic framework for evaluating the risk of inundation due to levee failure.

2. Numeric results based on an application to a single island that includes:
   A. Total probability of island/town inundation for specified future periods (e.g., 1, 10, 30, 50, and 100 years).

   B. Deaggregation of the total probability of inundation in terms of:
      1. Levee breaks (i.e., which levee sections are likely to lead to inundation).

      2. Failure modes (i.e., which failure modes dominate the probability of levee failure; overtopping, seismically induced liquefaction, embankment piping during periods of high flow).

As part of this effort we propose to take advantage of available data and existing studies in order to focus this effort on the development and application of a systems model to assess the probability of levee failure and inundation of areas.

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1. Introduction

1.1 Overview

This proposal defines the objectives and scope of a project to conduct a probabilistic risk assessment of the Sacramento-San Joaquin Delta (referred to hereafter as the Delta) levee system. As discussed here a risk assessment is an approach for evaluating the capability of an engineered system to perform a function for which it was intended. In this application the focus of the assessment is to evaluate the probability of levee failures and inundation of areas throughout the Delta (e.g., islands and communities). As compared to conventional engineering (deterministic) assessments, a risk assessment is a probabilistic statement about facility performance wherein the full range of loads (e.g., water levels, floods, seismic ground motions) and facility response to these loads is considered.

A risk assessment of the Delta levees provides the opportunity to:

- develop an understanding of the performance of the levee system (not just individual levees) in terms of the likelihood of failure and the cause of those failures,
- identify the most likely modes of levee failure,
- evaluate the probability that areas (e.g., islands, towns) will be inundated as a result of levee failure, and
- establish a consistent, rational approach to assess the benefit of proposed levee modifications or repairs.

The use of probabilistic methods to evaluate the integrity and future performance of a flood control system is a natural application. The inherent randomness of natural phenomena that challenge the integrity of a levee (e.g., floods, earthquake ground motion, degradation processes) and the inherent variability of levee materials, foundation characteristics and their construction, lead one to conclude that levee performance and the degree of protection they provide is uncertain.

We present in this proposal an approach that is well established in engineering practice, but new to the assessment of levee systems. The risk assessment methodology described is a major step forward in understanding the performance of the Delta levee system and the protection it provides the state. The systems based assessment will provide insights:

- to the causes of levee failure,
- the magnitude and probability of consequences (large and small) of inundation, and
- the significance of uncertainties.

When the risk assessment is applied to the current Delta levee system, it will provide direction for proposed modifications or repairs. When applied to a levee system as modified, a reevaluation of the levee risks will provide a basis for measuring the benefit (i.e., risk reduction) of implementing a proposed modification.

1.2 Probabilistic Risk Assessment Applications

Probabilistic risk assessments provide a consistent, rational framework to:

- identify and evaluate sources of uncertainty
- model the system performance of systems (as opposed to individual components)
- provide a realistic (neither conservative or unconservative) assessment of future performance,
- consider the full range of hazards a system may be exposed to (e.g., full range of earthquake ground motions, event combinations such as water levels and earthquake ground motions), not just design basis events, and
- the magnitude and probability of adverse consequences (e.g., economic losses, levee damage).

In recent years, the use of risk assessment methods in civil engineering applications has rapidly increased. Areas of application include evaluations for critical facilities such as dams and nuclear power plants, lifelines, development of operation and maintenance plans, assessment of public health risks (Refs. 1-5). This experience has produced an array of tools for evaluation and an experience base that has increased the efficiency in performing these assessments.

Integral to a probabilistic assessment of levee performance is the identification and evaluation of events that challenge a system's integrity and the assessment of the multiple ways failure can occur. The assessment evaluates the performance of a levee over the range of loads it may experience during its service life; loads above and below it's 'design basis.' Unlike 'conventional' construction (e.g., buildings), reliable performance of a levee system at or below it's design basis (e.g., design flood stage) cannot be assumed apriori. Therefore the potential for unsatisfactory performance over the full range of load conditions is required.

1.3 Project Team

This project will be carried out by Jack R. Benjamin and Associates, Inc. of Menlo Park, California. JBA has extensive experience in performing probabilistic risk assessments for critical facilities and civil infrastructures, including:

- dams
- nuclear power facilities
- levees
- pipelines

- tanks
- commercial and residential construction

At JBA this project will be managed by Dr. Martin W. McCann, Jr. In addition, Dr. McCann will be involved in all technical phases of the project. JBA's background and experience is provided in Appendix A.

Working with JBA will be Mr. Will Betchart, a water resources engineer with extensive experience in California and familiarity with both the Delta and the CALFED program. Mr. Betchart's background and experience is provided in Appendix B.

1.4 Proposal Scope

This proposal presents the purpose, scope and tasks for the project. In addition, a proposed schedule and budget is provided.

2. *Project Purpose*

The purpose of this project is:

1. Develop a probabilistic framework to evaluate the risk of inundation associated with the performance of levees in the Delta. A systems approach will be used to assess for the Delta (as a whole) and for individual communities, the risk of inundation due to levee failure. The systems approach is also used to model the performance of individual levees (i.e., a levee that protects an island). The methodology will consider the various hazards that challenge the integrity of the levee system, including multiple modes of failure.

2. Apply the methodology to an individual island to demonstrate its application and results.

3. Establish a framework for assessing and comparing the benefit of alternative levee modifications or repairs.

The results of this project (including its eventual application to the full levee system in the Delta) are intended to provide CALFED with a comprehensive, rational perspective of the anticipated performance of the levee system and the risk of inundation (and thus damages) at the local, regional and state levels. The nature of a risk assessment insures that events which can happen are considered in terms of their magnitude, consequence and likelihood of occurrence. It is within this context that a rational perspective of future events can be considered.

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3. Scope

3.1 Overview

The assessment of the Delta levee system will be performed to assess the probability of levee failure and inundation. A systems approach will be used that establishes a framework to address a range of questions related to the degree of protection provided by the levee system and the risk of inundation. The key questions the assessment will address include:

1. What is the risk (probability and magnitude) of inundation at the state level attributable to levee failure?

2. How likely is it that an area (e.g., island, town) will be inundated?

3. What are the likely locations of levee failures that result in inundation and what are the likely causes/modes of failure?

4. What are the risks of levee failure and inundation over a defined time horizon or service life?

5. What is the benefit (e.g., risk reduction) that can be attributed to a proposed modification (repair) of a levee and how can it be measured?

The first four questions can be addressed by conducting a comprehensive risk-based evaluation of the Delta levee system. The fifth question is answered by evaluating the levee system assuming proposed modifications are implemented and by developing a risk-based benefit measure.

The systems approach that will be used provides a logical framework to consider the potential combinations of events that could lead to inundation of an area (i.e., an island, town, etc.) and the range of failure modes that can result in the breach of a levee. For example, if a town is located at the confluence of two rivers, inundation of the town occurs if one or both levees along the town-side bank of either river failed. In addition, each levee could fail in a number of different modes. During periods of high flow, failure could occur as a result of overtopping, piping, embankment sliding, embankment slumping, excessive erosion. The objective of the systems part of the risk assessment is to develop a systems model to make these type of assessments.

The risk assessment in this study will be performed at two levels. The first will based on the current structure and condition of the levee system. The second will be conducted on the basis of proposed levee modifications. The risk reduction (i.e., the reduced likelihood of inundation) achieved by a levee modification will provide one measure of the benefit gained. As part of this project alternative measures of benefit will be considered.

3.2 Sources of Uncertainty

One of the important roles of a risk-based assessment is the identification and quantification of uncertainties. There are two fundamentally different sources of uncertainty that affect an assessment of the likelihood of future events. The first is attributed to the inherent randomness of events in nature (e.g., the toss of a coin, the occurrence of earthquakes in time and space). These events can only be predicted in terms of their likelihood of occurring. This source of uncertainty is irreducible and is known as **aleatory uncertainty**.

The second type of uncertainty is attributed to lack of knowledge or data. For example, the ability to determine the likelihood of an event (i.e., its rate of occurrence), requires certain data be available. If the amount of data is adequate, the estimate of a rate of occurrence will be accurate. On the other hand, if only limited data is available, the estimate of the rate will be uncertain (i.e., statistical confidence intervals will be large). A second source of knowledge uncertainty is attributed to our lack of understanding (e.g., knowledge) about a physical process or system that must be modeled. In these instances the engineer must use his/her professional judgement/experience to evaluate a problem or additional research must be conducted to improve process understanding. For example, DWR is now conducting important research to better understand the response of the Delta's peat soils to seismic shaking. These sources of uncertainty are referred to as **epistemic (knowledge-based) uncertainty**. Figure 1 shows two examples of epistemic uncertainties. In the one case the epistemic uncertainty in the estimate of the annual rate of occurrence of a magnitude 7.5 earthquake is quite large, whereas in the second case it is much smaller. The difference in these estimates may be attributed to the type and amount of data that was available, the extent to which judgement was used, etc.

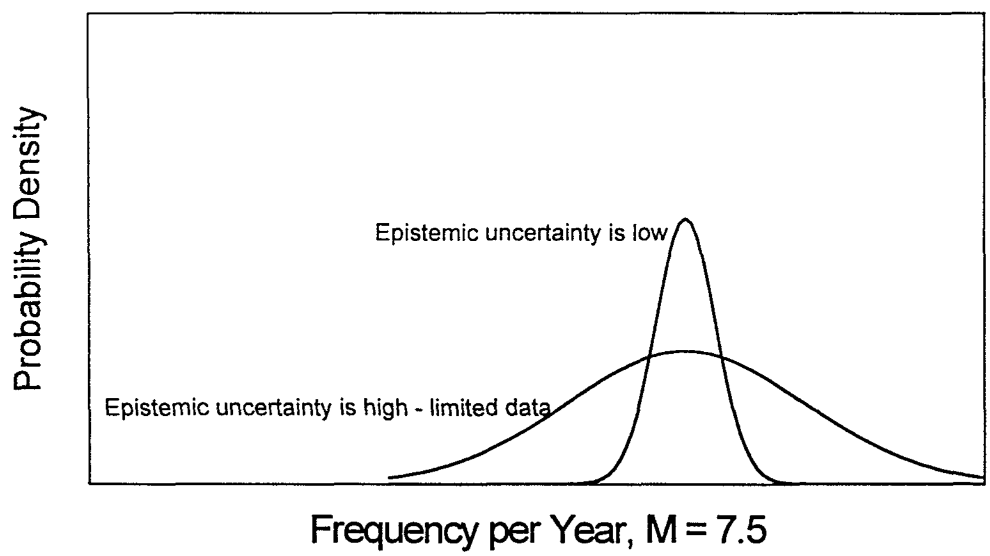

Figure 1 Illustration of estimates of the epistemic uncertainty in the annual rate of occurrence of a magnitude 7.5 earthquake.

In principle, epistemic uncertainties are reducible with the collection of additional data or the use/ development of improved models. In a given project, it is not always possible to reduce these uncertainties. However, it is important that both sources of uncertainty be identified and quantified to the degree possible.

The assessment of epistemic uncertainties can be critical. Their formal assessment requires a certain level of evaluation that adds defensibility and completeness. From a quantitative perspective, the assessment of epistemic uncertainties provides a best estimate of a desired result (e.g., probability of levee failure) and a probability distribution which can be used to develop the equivalent of confidence intervals. The probability distribution is based on an aggregation of the different sources of epistemic uncertainty (e.g., alternative models, uncertainties due to limited data, and alternative professional judgements). Such an assessment will be developed in the work we propose.

3.3 Technical Approach

In this section we discuss the technical issues and approach that will be used in this project to evaluate the reliability of the Delta levee system and the likelihood of inundation. Figure 2 shows a schematic of the elements in the Delta levee risk assessment. The elements of the risk assessment are:

1. Finalize the Risk Assessment Objectives
2. Hazards Identification and Assessment
3. Identify Components of the Levee System
4. Failure Modes and Effects Assessment
5. Systems Modeling
6. Vulnerability Assessment
7. Inundation Assessment
8. Consequence Assessment
9. Risk Quantification and Sensitivity Analysis

Each element of the risk assessment is described below.

Finalize the Risk Assessment Objectives - Like any engineering assessment the specific needs of the user (CALFED) of the analysis results must be clearly defined. Section 2 described the overall objectives of the risk assessment project. Within the context of these objectives, there are alternatives that can be considered or a variation in focus that may be required. Whereas the use of risk-based methods assessments is relatively new (as compared to more conventional engineering assessments, such as a slope stability evaluation for an embankment), it is important that the objectives and required products be clearly identified. Examples of issues/objectives that can be discussed, include:

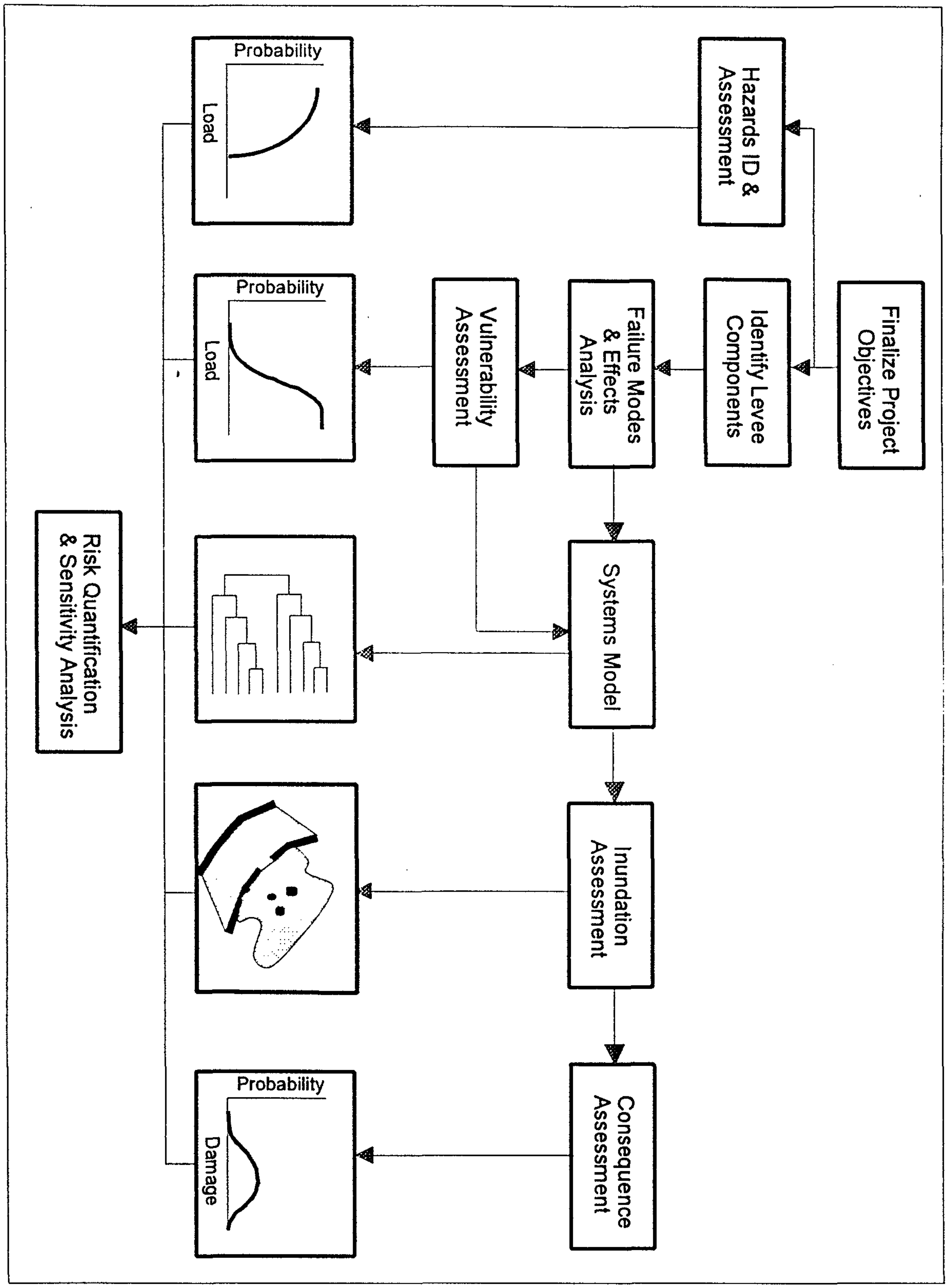

Figure 2 Elements of the Delta risk assessment.

- selecting the time horizon or service life for purposes of making future projections,
- identifying the specific final and intermediate results that should be computed/ reported, and
- clarifying the study assumptions (pre-conditions)

These will be discussed and finalized at a meeting early in the project.

Hazards Identification and Assessment - As a first step in the risk assessment, a list of the hazards to which a levee is exposed will be generated. This list will include events that by themselves or in combination may challenge the integrity of a levee. Table 1 contains an initial list of events. As part of this process, our analysis will list the nature of the hazard/load (e.g., ground shaking), related hazards (e.g., seiche), and potential combinations with other hazards (e.g., high-water levels). Resources or information requirements to evaluate the hazard will be identified and the appropriate assessments performed.

Table 1
Potential List of Hazards/Loads to be Considered

Seismic Events	Subsidence
Ground Motion	
Fault Offset	Non-Flood Stage
Seiche	Water Level
Liquefaction	Seepage
Floods	Deterioration
Overtopping	Erosion
Wave Action	Wave Action
Piping	

This part of the assessment serves a number of objectives. It identifies the potential hazards the levee system may be exposed to, screens out the hazards that do not pose a threat (i.e., they are too small in magnitude or are unlikely to occur) and evaluates the probability of occurrence and magnitude of those that must be considered in the risk assessment.

Identify Components in the Levee System - The purpose of this part of the assessment is to establish an inventory of the components in the Delta flood control system. The task here is to establish an inventory of only those components that play a role in providing flood protection.

Failure Modes and Effects - In this part of the assessment each component in the flood control system and its function is systematically identified (e.g., reach of levee, type of foundation). In addition the modes of failure and the effects (i.e., consequence) of a failure are documented. As part of this assessment consideration will be given to:

- failures and effects that may be unique to specific hazards (e.g., salt water inundation as compared to fresh water),
- multiple failures that may have compound consequences (e.g., inundation and disruption of fresh water conveyance),
- alternative failure locations, and
- conditions (generally stated) for failure to occur.

This analysis is an important part of the risk assessment (Ref. 6). It puts into context the role that each component plays in the system and the impact of its failure. The results of this assessment will be a direct input to the systems evaluation.

Systems Modeling - In this project a systems approach will be used to develop a logic model that describes the events that can lead to levee failure and inundation in the Delta. Well developed techniques including event tree and fault tree methods (Ref. 1, 6), and lifeline analysis methods (Ref. 3) will be used to model the events that can lead to levee failure and inundation. These techniques provide an ordered approach to system model construction, graphical display and quantification. They are particularly useful, even mandatory, in cases involving large, complicated situations where multiple events can/must occur.

The use of one modeling approach over another will vary depending on the hazard type (e.g., seismic, static, non-flood conditions) and the system. For example, in the case of seismic performance of the levee system, a lifeline analysis technique will be used. These methods have been specifically developed to model the reliability of spatially distributed systems when exposed to earthquake ground motion. They may also be suited to the assessment of levee performance during a hydrologic (flood) event.

For static, non-flood conditions, event and fault tree methods will likely be used.

The development of the Delta systems model will be carried out using a top-down approach. In this approach a model is constructed by first considering the major events whose probabilities are to be determined. Figure 3 shows a schematic of the top-down approach. In this project we propose to consider as a top event, the evaluation that flooding anywhere in the Delta will occur due to levee failure in a specified time horizon. To make this determination, the model must also address the potential that various areas (e.g., towns, islands) will be inundated. Continuing further, the system model then considers the levees whose breach can lead to inundation of a particular town, the individual levee reaches where failure might occur and the events/failure modes that cause a breach.

The use of a top-down approach is advantageous for a number of reasons. First, it focuses the

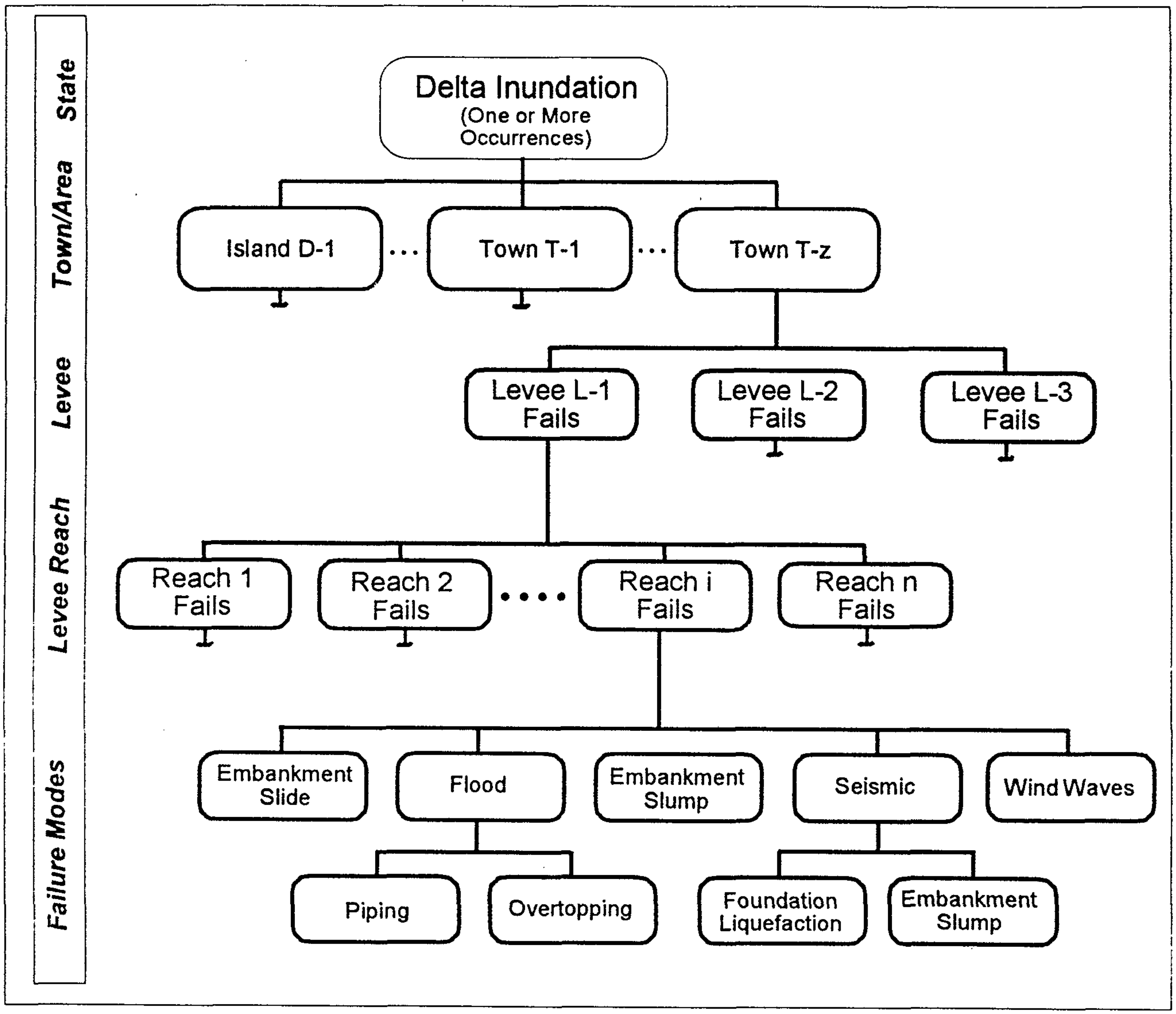

Figure 3 Illustration of top-down systems modeling approach to be used in the Delta risk assessment.

evaluation on the questions/events of primary interest. Secondly, the top-down approach allows the analyst to build the systems model to the level of detail required. In this way resources are focused on the evaluations that are important to the objectives of the assessment.

The systems model is constructed in manner that permits the quantification of the desired results (i.e., answers to the question raised above). For example, depending on the scope of the risk assessment, the systems model can be built to evaluate the probability and magnitude of the consequences (e.g., economic losses, property damage) of levee failure and flooding. If however, the objective is simply to evaluate the likelihood of levee failure, the systems model is built only to this point (i.e., the inundation and consequence parts of the model are not considered) (see Fig. 2).

The systems approach provides a logical path to the events that are the dominant cause and contributors to levee failure, flooding and their consequences. It makes the analysis tractable for the engineer who must use the results and for management who requires an understanding of the events that influence the reliability of the system.

Vulnerability Assessment - In this part of the risk assessment each component is evaluated to determine the probability of failure of a levee as a function of the loads or hazards it may be exposed to. For example, in the case of seismic events, a levee will be evaluated to determine the probability of failure as a function of earthquake ground motion level. This assessment must consider the multiple modes of failure that may exist such as foundation liquefaction, slope instability, consolidation, etc. and the sources of variability in levee response to ground motion. This result is a seismic fragility curve that quantifies the conditional probability of failure as function of ground motion level. Figure 4 shows an example of a seismic fragility curve. At low ground motion levels, the chance of failure is low (at or near zero). As ground motions increase, there is an increasing chance of failure. Finally, a point is reached whereby failure is certain (see Fig. 4). The shape and position of a fragility curve depends on the seismic capacity of the levee (see the median capacity noted in Figure 4) and the variability in its response (e.g., material properties, dynamic response characteristics) to earthquake ground motions.

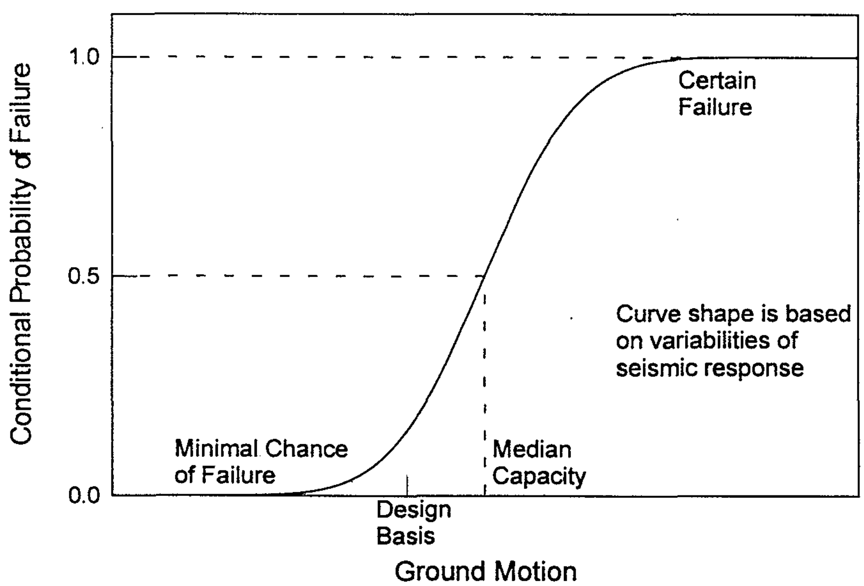

Figure 4 Illustration of seismic fragility curve for a single component.

To assess the vulnerability of levees there are a number of factors/issues that must be addressed. Among them are:

- modeling the potential for levee failure at any point along its length
- accounting for random failures that cannot be evaluated due to lack of information

(i.e., geotechnical data) or engineering tools to estimate there probability of occurrence, and

- the variation in levee integrity in time due to the effects of deterioration, subsidence, etc.

A vulnerability assessment is conducted for each component in the system and for each of the hazards/loads the system is exposed to.

Inundation Assessment - The purpose of this part of the risk assessment is to determine the extent of flooding in the event of a levee break. An assessment of the area of inundation can be based on historic experience or possibly the result of a detailed hydraulic assessment (e.g., NWS DAMBRK). Inundation assessments are required for the postulated levee breach scenarios (e.g., failure mode and levee reach) that are defined in the systems model.

Consequence Assessment - The purpose of the consequence assessment is to evaluate the impact (i.e., property damage, effect on the local economy, damage to fresh water supplies, etc.) that may result from potential levee failures and subsequent inundation. The systems approach to modeling the levee system lends itself to an evaluation of consequences for specified conditions, including time of year, water level, failure mode and location, etc. The consequences to be evaluated are identified early in the project when the study objectives are finalized.

We have identified the consequence part of the risk assessment as one element that can be readily incorporated in the systems analysis. For purposes of this initial project, it is anticipated that the consequences of inundation will not be assessed.

Risk Quantification and Sensitivity Analysis - In this part of the risk assessment, the individual parts of the analysis are combined to generate the analysis products (discussed in Section 5). The quantification can be carried out at different levels depending on the study objects. In addition, sensitivity assessments are performed to examine to role of different assumptions, parameter assessments, etc. in the study.

3.4 Benefits Assessment

As part of this project an approach will be developed to provide a measure of the benefit of levee modifications that may be proposed. A number of alternatives can be considered, depending on decision criteria CALFED may want to use (e.g., cost/benefit ratios) and the time horizon for the study. A simple benefit measure might be ratio of levee failure probabilities which provides a measure of risk reduction. A more rigorous approach may be taken based on the cost-benefit of proposed modifications, taking into account engineering and construction costs, avoided losses due to the reduced likelihood of levee failure, etc. The development of a benefit measure will be carried out in consultation with CALFED personnel. These consultations will serve to identify CALFED's objectives (i.e., maximize risk reduction, minimize costs), preferences, etc. Based on these discussions an approach for measuring the benefit of levee modification will be developed.

3.5 Project Resources

In carrying out the demonstration risk assessment for a selected island, we propose the use of available data (e.g., geotechnical properties, flood data, seismic hazard information) as well as the results of prior evaluations that may be available (see Ref. 7-10). As necessary and appropriate, existing engineering calculations will be repeated to support the needs of the risk assessment. From a project scope and budget perspective, we propose that the demonstration assessment identify areas that will be inundated in the event of levee failure, based on past experience and engineering judgement as required (i.e., detailed inundation assessments will not be performed). This effort will focus on the probabilistic assessment of levee performance and likelihood of failure, utilizing available information to the greatest extent possible.

4. *Project Tasks*

To carry out the project scope the following tasks will be performed:

1. Finalize the Risk Assessment Objectives
2. Develop the Probabilistic Framework to Model the San Joaquin Delta Levee System
3. Gather Data
4. Select One Island or Levee For a Demonstration Application
5. Perform the Risk Assessment for the Demonstration Levee
6. Develop a Framework for Measuring the Risk Reduction of Levee Modifications
7. Identify Levee Modifications
8. Reevaluate Levee Failure Probabilities Based on a Proposed Modification
9. Quantify Modification Benefits
10. Prepare the Draft Report
11. Finalize the Project Report
12. Project Meetings

Table 3 provides a summary of each task.

Table 2
Summary of Project Tasks

No.	Task	Description
1	Finalize the Risk Assessment Objectives	The purpose of this task is to meet with CALFED personnel to specifically identify the objectives of the risk assessment in terms of questions to be answered, results to be generated. (See the text for additional explanation.)
2	Develop the Probabilistic Framework for the Risk Assessment	In this task the complete framework for evaluating the probability of levee failure and area inundation will be developed. The framework will consider the hazards/loads (e.g., flooding, earthquake ground shaking, static/gravity loads) that can initiate a levee failure. As part of the framework development, the methods to evaluate different modes of failure, the occurrence of hazards, etc. and data resources will be identified. (See the text for additional discussion of this task.)
3	Gather Data	In this task data and results of previous studies that can provide input to the risk assessment will be gathered.
4	Select a Levee for the Demonstration Assessment	In consultation with CALFED, a levee will be selected for the demonstration application.
5	Perform the Risk Assessment for the Demonstration Levee	In this task the levee risk assessment is performed.
6	Develop a Framework for Measuring the Benefit of Levee Modifications	In this task an approach for quantifying the risk reduction benefit gained by the levee modification will be developed. Alternatives include failure probability ratios, annualized economic benefits or total benefits over the service life of the levee, etc.
7	Identify Levee Modification	Based on the results of the risk assessment, CALFED engineers will be consulted to define a proposed modification. In this project, it is assumed that CALFED engineers will select the appropriate levee modification to be considered. (An actual modification design will not be prepared by the risk assessment team.)
8	Reevaluate the Levee Failure Probabilities	The risk of levee failure and inundation will be reevaluated based on the levee modification proposed by CALFED.
9	Quantify Modification Benefits	In this task the benefits of the levee modification are assessed.
10	Prepare the Draft Report	Prepare the project draft report describing the risk assessment methodology and demonstration application, including applicable data.
11	Finalize the Report	Finalize the project report based on comments recieved.
12	Project Meetings	During the project it is anticipated that a number of meetings (approximately four (4)) will be held with CALFED personnel. The timing for these meetings is preliminary and is indicated on the proposed project schedule provided in Figure 7.

5. Products

In this section we identify products that will be generated in this project. The final list of products will be developed to meet the project objectives, which will be finalized as part of the first task (see Table 2).

From a methodological perspective, two products will be developed:

1. Probabilistic framework for conducting a systems-based analysis for modeling the potential for levee failure and inundation in the Delta.

2. Probabilistic methodology for evaluating the multiple modes of levee failure.

3. Approach to assess the benefit of proposed levee modifications or repairs.

The risk assessment will generate a suite of numeric results that address a hierarchy of questions related to levee performance in the Delta and the risk of inundation at the state and local level. One of the requirements for making the results of a risk assessment usable (e.g., to the staff engineer, management) is that it be tractable and transparent. With this in mind, a spectrum of results can be presented that are designed to support decision-making and to provide the engineer with a detailed understanding of the risk assessment results as well as the events (e.g., failure modes) that contribute to the potential for levee failure and inundation. Numeric results generated as part of the risk assessment will include:

1. Total probability that one or more areas will be inundated in specified time horizons (i.e., 1, 10, 30, 50, and 100 years) - This result provides a measure of the exposure of the Delta to inundation due to unsatisfactory performance of the levee system. Table 3 illustrates this result. In a similar manner this result will be determined assuming that proposed modifications/repairs are implemented.

Table 3
Illustration of Risk Assessment Results
Probability of One or More Areas in the Delta Being Inundated [1]

Result	**Future Time Period (years)**				
	1	**10**	**30**	**50**	**100**
Present (wo/modifications)	0.05	0.20	0.50	0.98	1.0
Future (w/modifications)	.02	0.15	0.30	0.65	0.95

[1]Numbers are for illustration only.

2. Total probability of island/town inundation for specified time horizons (e.g., 1, 10, 30, 50, and 100 years) - This result, which can be presented in a format similar to Table 3, quantifies the risk of inundation for an area or community. This result can be presented for each area identified in the study.

3. Deaggregation of the total probability of inundation in terms of:

   A. Levee breaks - This result provides a breakdown of the failure probability of each levee reach. An example of this type of result is displayed in Figure 5.

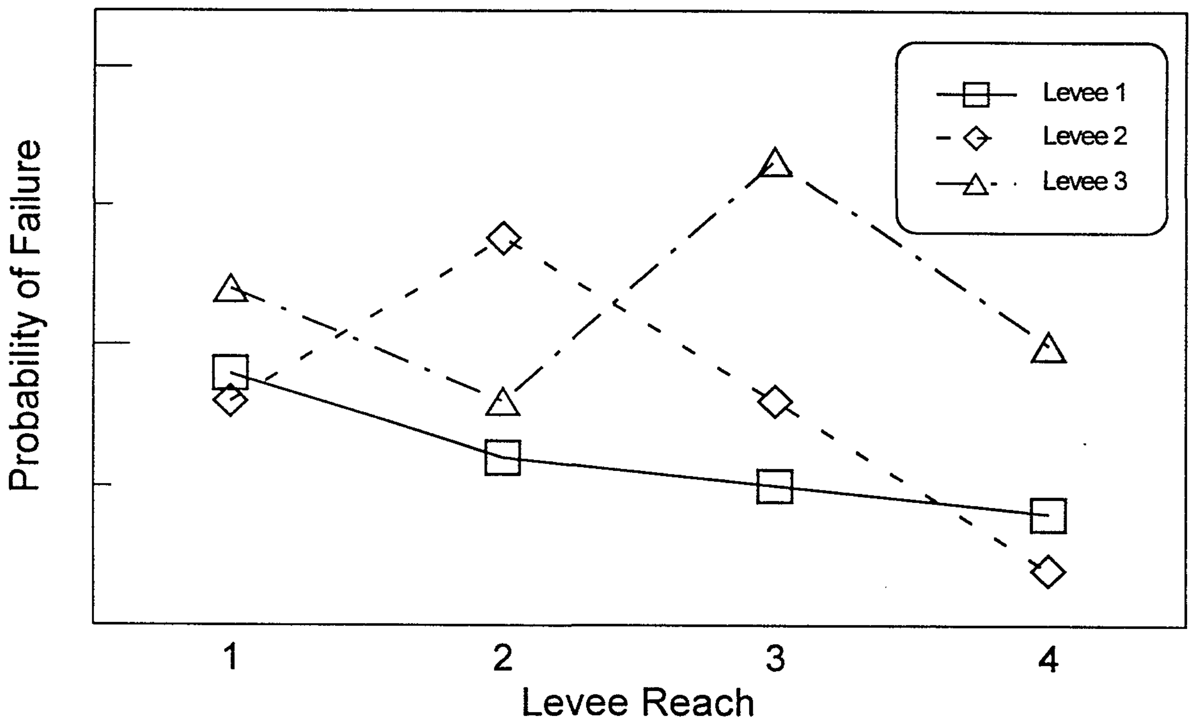

Figure 5 Levee reach failure probabilities.

   B. Failure modes - When considering possible modifications or repairs to a levee, it will be important to a have a balanced perspective of the relative contribution of different failure modes such as overtopping, seismically induced liquefaction, embankment piping during periods of high flow, etc. to the total probability of levee failure. For example, Figure 6 shows an example of the relative contribution of different hazards/failure modes to the failure probability of a levee. This type of result can be presented for a single levee (i.e., that protects an island) or for the entire levee system.

4. Variation of the probability of levee failure for various time horizons - The potential for

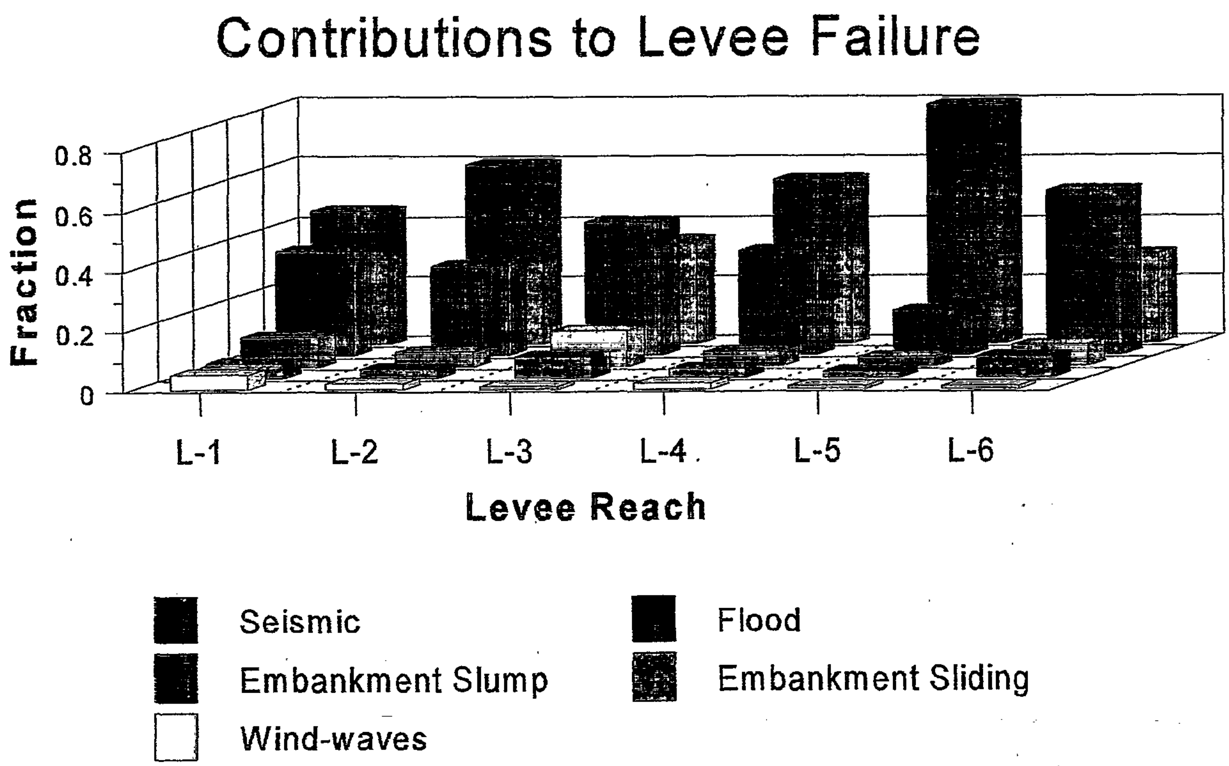

Figure 6 Relative contribution of different failure modes/events to the probability of levee reach failure.

deterioration and increased hazard potential (e.g., seismic events) may increase the likelihood of levee failure in time. The purpose of this result is to identify whether this is the case. If so, this result will support future plans to modify existing levees and to provide for future maintenance.

5. Measure of the benefit of proposed levee modifications - This result will provide a metric of the benefit, in terms of risk reduction, of proposed levee modifications. Depending on the approach that is developed, the metric will be applied at the State (i.e., a measure of the benefit to the State as a whole) or to a local area or community.

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6. Schedule

We propose a project duration of four (4) months from the start date to delivery of the draft report. The schedule and duration of each task is shown in Figure 7. As part of the project we plan to prepare an interim letter report 6 weeks into the project to document progress to date.

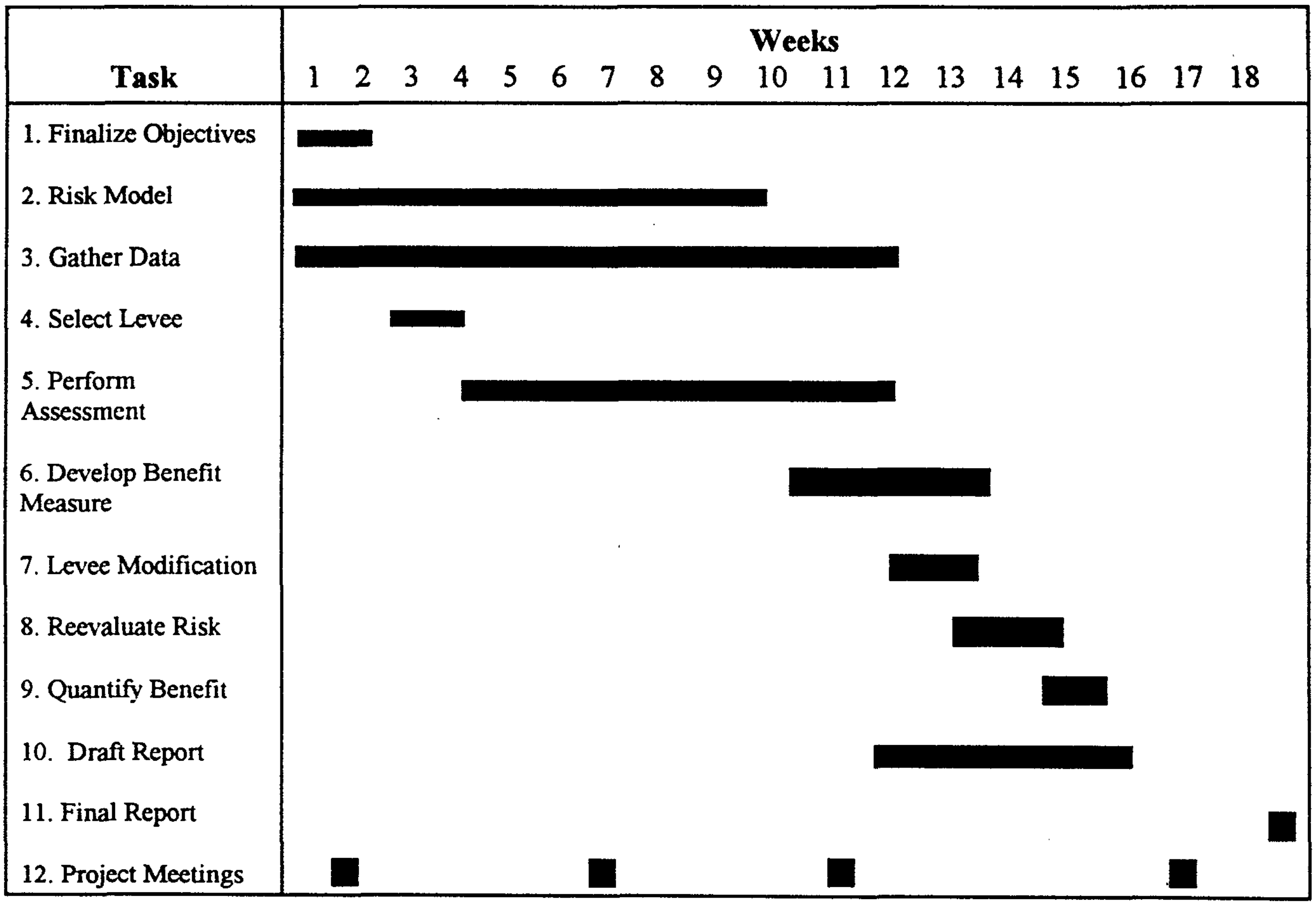

Figure 7 Proposed project schedule.

7. *Budget Estimate*

We have prepared a project budget based on our best estimate of the level of effort and expenses required to carry out the project tasks. We estimate a total project budget of $50,000. Table 4 summarizes the estimated project costs by task.

Table 4
Summary of the Proposed Project Budget

Task	Proposed Cost
1. Finalize the Risk Assessment Objectives	$2,000
2. Develop the Probabilistic Framework for the Risk Assessment	9,600
3. Gather Project Data	2,000
4. Select a Levee for a Demonstration Assessment [1]	500
5. Perform the Risk Assessment	16,000
6. Develop a Framework for Measuring the Benefits of Levee Modifications	3,000
7. Identify Levee Modifications [2]	500
8. Reevaluate Levee Failure and Inundation Probabilities	4,700
9. Quantify Modification Benefits	1,200
10. Prepare Draft Report	7,000
11. Finalize the Project Report	1,500
12. Project Meetings	2,000
Total	**$50,000**

[1] It is assumed that CALFED will assist in this selection.
[2] It is assumed that CALFED will define the proposed modification.

8. *References*

1. McCann, Jr., M.W., et. al., "PRA Procedures Guide, NUREG/CR-2815, prepared for the U.S. Nuclear Regulatory Commission, 1985.

2. Barlow, R.E. and H.E. Lambert, "Introduction to Fault Tree Analysis," in Reliability and Fault Tree Analysis, ed. R.E. Barlow, J.B. Fussell, and N.D. Singpurwalla, Society for Industrial and Applied Mathematics, Philadelphia, Pennsylvania, 1975.

3. Yucemen, M.S. and A.S. Selcuk, "Earthquake Reliability of Lifeline Networks," Proceeding of the Fifth U.S. National Conference on Earthquake Engineering, Chicago, Illinois, 1994.

4. U.S. Department of Transportation, "Pontis", Technical Manual, FHWA-SA-94-031, December 1993.

5. Salmon, G. M., "Integrating Risk Assessment Into a Dam Safety Program," Keynote Address, IPENZ Proceedings of Technical Group 21/1 (LD), 1995.

6. Henley, E.J. and H. Kumamoto, Reliability Engineering and Risk Assessment, Prentice-Hall, Englewood Cliffs, N.J., 1981.

7. California Department of Water Resources, "Seismic Stability Evaluation of the Sacramento-San Joaquin Delta Levees, Sacramento, California, August 1992.

8. Earth Science Associates, Inc., "Geotechnical Investigation, Earthquake Safety Assessment of the Mokelumne Aqueduct San Joaquin Delta Crossing," ESA Project 3439K, August 1992.

9. Working Group on California Earthquake Probabilities, "Probabilities of Large Earthquake in the San Francisco Bay Region, California," U.S. Geological Survey Circular 1053, 1990.

10. Ake, J., J. Wilson, D. Ostenaa, and R. LaForge, "Preliminary Seismic Risk Analysis for the Delta Water Management Study, North Delta," Seismotectonic Report 91-3, U.S. Bureau of Reclamation, Denver, Colorado, 1991.

Appendix A

JBA Background and Experience

D-031265

STANDARD FORM (SF) **254** Architect Engineer and Related Services Questionnaire	1. Firm Name / Business Address Jack R. Benjamin & Associates, Inc. 530 Oak Grove Avenue, Ste. 101 Menlo Park, CA 94025 1a. Submittal is for ☒ Parent Company ☐ Branch or Subsidiary Office	2 Year Present Firm Established 1979	3. Date Prepared February 14, 1997

4. Specify type of ownership and check below, if applicable
Corporation

X	A.	Small Business
	B.	Small Disadvantaged Business
	C.	Women-owned Business

5. Name of Parent Company, if any:

Jack R. Benjamin & Associates, Inc.
530 Oak Grove Avenue Suite 101
Menlo Park, CA 94025

5a. Former Parent Company Name(s), if any, and Year(s) Established:

6. Names of not more than Two Principals to Contact: Title / Telephone

1) Dr. Martin W. McCann, Jr. President (415) 473-9955
2) Dr. Jack R. Benjamin, Chairman (415) 473-9955

7. Present Offices: City / State / Telephone / No. Personnel Each Office

7a. Total Personnel 4

City / State	Telephone	No. Personnel
Menlo Park, CA	(415) 473-9955	4

8. Personnel by Discipline: (*List each person only once, by primary function.*)

1	Administrative		Electrical Engineers		Oceanographers		
	Architects		Estimators		Planners: Urban/Regional		
	Chemical Engineers		Geologists		Sanitary Engineers		
2	Civil Engineers		Hydrologists		Soils Engineers		
	Construction Inspectors		Interior Designers		Specification Writers		
	Draftsmen		Landscape Architects	1	Structural Engineers		
	Ecologists		Mechanical Engineers		Surveyors		
	Economists		Mining Engineers		Transportation Engineers		

9. Summary of Professional Services Fees Received (Insert Index Number)

Last 5 Years (most recent year first)

	1996	1995	1994	1993	1992
Direct federal contract work, including overseas	0	1	1	1	1
All other domestic work	2	4	4	4	4
All other foreign work	1	1	2	2	2

Firms interested in foreign work, but without such experience, check here : ☐

Ranges of Professional Services Fees

INDEX	
1.	Less than $100,000
2.	$100,000 to $250,000
3.	$250,000 to $500,000
4	$500,000 to $1 million
5.	$1 million to $2 million
6.	$2 million to $5 million
5	$5 million to $10 million
6.	$10 million or greater

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10. Profile of Firm's Project Experience, Last 5 Years								
Profile Code	Number of Projects	Total Gross Fees	Profile Code	Number of Projects	Total Gross Fees	Profile Code	Number of Projects	Total Gross Fees
1) 095	15	1929	11)			21)		
2) 200	11	530	12)			22)		
3) 201	20	803	13)			23)		
4) 202	1	75	14)			24)		
5) 203	4	100	15)			25)		
6) 204	1	110	16)			26)		
7)			17)			27)		
8)			18)			28)		
9)			19)			29)		
10)			20)			30)		

11 Project Examples, Last 5 Years

Profile Code	**"P" "C" "JV" of "IE"**	**Project Name and Location**	**Owner Name and Address**	**Cost of Work (in thousands)**	**Completion Date (actual or estimated)**
024, 201, 203	C	1. Probabilistic Risk Assessment for Seven Mile Dam	Klohn-Crippen Ltd. 610 Burrard Street Vancouver, British Columbia	50	12/97
200	P	2. Seismic Hazard Assessment for the Tomari Nuclear Power Plant - Hokkaido Island	Obayashi Corporation Nuclear Engineering Division Shinjuku Tower Tokyo, Japan	175	12/97
025, 201	P	3. Probabilistic Risk Assessment for Par Pond Dam, Savannah River Site	Westinghouse Savannah River Company Aiken, SC 29803	39	5/92
074, 200, 201	P	4. Umatilla, Pine Bluff & Pueblo Chemical Demilitarization Facility Seismic Probabilistic Safety Assessment - perform seismic hazard assessment, walkdowns and fragility analysis	SAIC (Prime Contractor to U.S. Army) 1309 Continental Drive Suite F Abingdon, MD 21009	426	3/96
024, 025, 200, 201, 203	C	5. Probabilisitic Risk Assessment for the San Diego Water Authority Emergency Storage Project	GEI Consultatns, Inc. (Prime to San Diego Water Authority) 1925 Palomar Oaks Way, Ste 300 Carlsbad, CA 92008	54	11/94

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201, 204	P	6. Development of the Nuclear Industry Posistion for Seismic Design of Nuclear Power Facilities	Electric Power Research Institute 2314 Hillview Ave. Palo Alto, CA 94303	110	12/94
074, 200, 201, 095	C	7. Tooele Chemical Demilitarization Facility Seismic Probabilistic Safety Assessment - perform seismic hazard assessment, walkdowns and fragility analysis.	SAIC (Prime Contractor to U.S. Army) 1309 Continental Drive Suite F Abingdon, MD 21009	530	6/95
095	C	8. Point Beach USI A-46 and IPEEE project - Flood Hazard and Vulnerability Assessment	Stevenson & Associates , Inc. (Prime Contractor to Wisconsin Electric Power Co.) 10 State St., Woburn, MA 01801	75	6/95
071, 095, 203	C	9. Palisades USI A-46 and IPEEE project - Systems Analysis for Seismic Risk Evaluation	Stevenson & Associates , Inc. (Prime Contractor to Consumers Power Co.) 10 State St., Woburn, MA 01801	57	6/95
095	P	10. Development of Electric Power Industry Position and Approach for Determining the Seismic Design Basis for Nuclear Power Plants	Electric Power Research Institute 2314 Hillview Ave. Palo Alto, CA 94303	150	12/94
095	P	11. Re-write of the EPRI Seismic Margins Methodology Report	Electric Power Research Institute 2314 Hillview Ave. Palo Alto, CA 94303	80	12/94
200, 201	P	12. Development of Seismic Hazard Assessment Diagnostic Tools	Lawrence Livermore National Laboratory, Livermore, CA	65	12/94
071, 095, 203	C	13. Pilgrim Station Seismic PRA and USI A-46 and IPEEE project - A-46 walkdowns and analyses, seismic fragilities, building dynamic analysis with soil structure interaction, outlier resolution, and final report	Stevenson & Associates, Inc. (Prime Contractor to Boston Edison Co.) 10 State St., Woburn, MA 01801	85	9/94
071, 095	C	14. Fort Calhoun USI A-46 and IPEEE project - A-46 walkdowns and analyses, seismic fragilities and Seismic margins analyses, outlier resolution, and final report	Stevenson & Associates, Inc. (Prime Contractor to Omaha Public Power Dept.) 10 State St., Woburn, MA 01801	40	4/94
200	P	15. Probabilistic Seismic Hazards Assessment for Two Sites in Tennessee	Tennessee Valley Authority Knoxville, Tennessee	65	12/93

12. The foregoing is a statement of facts

Signature [signature] Typed Name and Title Martin W. McCann, Jr. , President Date: February 27, 1997

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STANDARD FORM (SF) **255** Architect Engineer and Related Services Questionnaire for Specific Project	1. Project Name/Location for which Firm is Filing	2a. *Commerce Business Daily* Announcement Date, if any:	2b. Agency Identification Number, if any:
	Probabilistic Risk Assessment for the Sacramento-San Joaquin Delta Levee System	February 26, 1997	

3. Firm (or Joint-Venture) Name & Address

Jack R. Benjamin & Associates, Inc.
530 Oak Grove Avenue, Suite 101
Menlo Park, CA 94025

3a. Name, Title & Telephone Number of Principal to Contact

Martin W. McCann, Jr. (415) 473-9955
President

3b. Address of office to perform work, if different from Item 3

4. Personnel by Discipline: (List each person only once, by primary function.) Enter proposed consultant personnel <u>to be utilized</u> on this project on line (A) and in-house personnel on line (B). (Includes all team members)

(A)	(B)		(A)	(B)		(A)	(B)		(A)	(B)	
	1	Administrative			Electrical Engineers			Oceanographers			
		Architects			Estimators			Planners: Urban/Regional			
		Chemical Engineers			Geologists			Sanitary Engineers			
1	2	Civil Engineers			Hydrologists			Soils Engineers			
		Construction Inspectors			Interior Designers			Specification Writers			
		Draftsmen			Landscape Architects		1	Structural Engineers			
		Ecologists			Mechanical Engineers			Surveyors			
		Economists			Mining Engineers			Transportation Engineers	1	4	Total Personnel

5. If submittal is by JOINT-VENTURE list participating firms and outline specific areas of responsibility (including administrative, technical and financial) for each firm: (Attach SF 254 for each if not on file with Procuring Office)

Not Applicable

5a. Has this Joint-Venture previously worked together? ☐ Yes ☐ No

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6. If respondent is not a joint-venture, list outside key Consultants/Associates anticipated for this project (attach SF 254 for Consultants/Associates listed, if not already on file with the Contracting Office)

Name & Address	Specialty	Worked with Prime before (Yes or No)

7. Brief Resume of **Key** Persons, Specialists, and Individual Consultants Anticipated for this Project
a. Name and Title: Jack R. Benjamin, Chairman
b. Project Assignment: Risk-Based Analysis
c: Name of Firm with which associated: Jack R. Benjamin & Associates, Inc.
d. Years of experience: With This Firm: 17 With Other Firms: 37

e. Education	Degree(s)/Year/Specialization
Massachusetts Institute of Technology	Sc.D./1942/Civil Engineering
University of Washington	M.S./1940/Civil Engineering
University of Washington	B.S./1940/Civil Engineering

f. Active Registration: Year First Registered/Discipline

1955/Civil Engineer

g. Other Experience and Qualifications relevant to the proposed project:

Jack R. Benjamin & Associates, Inc., Menlo Park, CA (since 1979)

Dr. Benjamin is a founder and chairman of Jack R. Benjamin & Associates, Inc. He has over 50 years of experience as a civil/structural engineer in consulting practice. He is a leader in the application of probabilistic methods and decision theory in civil engineering. He is the co-author of the book, "Probability, Statistics and Decision for Civil Engineers." This book is in fact one of the references noted in the Corps of Engineers engineering circular EC 1105-2-205, "Risk-Based Analysis for Evaluation of Hydrology/Hydraulics and Economics in Flood Damage Reduction Studies."

Dr. Benjamin is Professor Emeritus of Civil Engineering at Stanford University where he served on the faculty for 28 years.

Since 1974, after retiring from Stanford, Dr. Benjamin has been involved in engineering practice. As a leader in the application of probabilistic and decision analysis methods, he has been involved in many applications at the early stages of their development. One of his projects at JBA was a research effort funded by the National Science Foundation entitled, "Reliability Assessment for Levee Lifeline Systems."

Working as a consultant to the East Bay Municipal Utilities District, Dr. Benjamin evaluated the integrity of levees and pipeline crossngs for seismic and flood events for the Mokelume Aqueduct in the San Joaquin Delta.

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7. Brief Resume of **Key** Persons, Specialists, and Individual Consultants Anticipated for this Project

a. Name and Title: Martin W. McCann, Jr., President

b. Project Assignment: Risk-Based Analysis

c: Name of Firm with which associated: Jack R. Benjamin & Associates, Inc.

d. Years of experience: With This Firm: 17 With Other Firms: 0

e. Education	Degree(s)/Year/Specialization
Stanford University	Ph.D./1980/Civil Engineering
Stanford University	M.S./1976/Structural Engineering
Villanova University	B.S./1975/Civil Engineering

f. Active Registration: Year First Registered/Discipline

None

g. Other Experience and Qualifications relevant to the proposed project:

Jack R. Benjamin & Associates, Inc., Mountain View, CA (since 1979)

Dr. Martin W. McCann, Jr. is a founder and President of Jack R. Benjamin & Associates, Inc. From 1984 to 1989 he served as Vice President of the corporation. His professional background includes probabilistic hazards analysis (including seismic and hydrologic events), reliability and risk assessment, systems analysis, and seismic engineering.

Dam, Water Resources and Flood Hazard Assessment Projects

Currently Dr. McCann is a consultant and reviewer to British Columbia Hydro for a risk assessment being conducted for Seven Mile Dam. The study is considering all hazards the dam may be exposed to and the performance of mechanical and electrical equipment as well as civil structures. Dr. McCann is assisting with the methodology to be used in the study, the review of the program scope and task statements, and the development of logic models to be used in the analysis.

Following the tainter gate failure at Folsom Dam, Dr. McCann was retained by the Sacramento Area Flood Control Agency (SAFCA) to prepare an initial work scope and budget for a reliability assessment for Folsom Dam.

As part of a planning study, the San Diego County Water Authority (SDCWA) considered alternative designs for an Emergency Storage Project (ESP). To support this study, an evaluation was conducted in which a safety goal (SG) for the performance of dams was recommended. The SG established minimum performance and reliability levels for dams that are considered a part of alternative ESP system designs. Once the SG was selected, the risk assessment focused on the characteristics that must be provided by the design of a dam so that a reasonable assurance exists that the SG is fact met. As an example, for seismic events the risk assessment determined the ground motion level that a dam must be capable of withstanding in order to provide the required level of reliability.

As part of the Department of Energy (DOE) and Lawrence Livermore National Laboratory (LLNL) natural phenomena hazards project, Dr. McCann prepared the flood design criteria in <u>Design and Evaluation Guidelines For Department of Energy Facilities Subjected to Natural Phenomena Hazards</u>, UCRL-15910. He was the course lecturer for the flood part of the DOE workshop on natural phenomena hazard. The workshop addresses the DOE flood design guidelines, probabilistic flood hazard assessment and flood design strategies.

Under the direction of Dr. McCann, JBA performed a probabilistic flood hazard assessment for the DOE Hanford Reservation, located adjacent to the Columbia River. The flood hazard assessment considered the possibility of extreme flood events and upstream dam failure as potential causes of onsite flooding.

Dr. McCann was the project manager of a study to evaluate the risk of failure of three lock and dam structures on the Upper Ohio River for the Pittsburgh District. This study was concerned with a 25-year projection of the frequency of the loss of function of the navigation locks due to natural and man-made hazards.

Dr. McCann directed a preliminary probabilistic risk assessment for PAR Pond Dam at the Department of Energy Savannah River Site. The study included an assessment of the frequency of dam failure due to seismic, hydrologic, and static load events.

As a subcontractor to Sandia National Laboratories for the USNRC Unresolved Safety Issue on Decay Heat Removal, JBA performed probabilistic flood studies at a number of nuclear power plant sites. These studies involved an assessment of the frequency of extreme floods and the frequency of core damage.

Seismic Risk Assessment Projects

As part of a study at the DOE Savannah River Site, Dr. McCann was the project manager of a program to evaluate the risk to nuclear reactor facilities due to seismic events. JBA provided the seismic hazard and fragility input to the risk assessment. In addition, JBA conducted the risk quantification calculations, using software developed at JBA. For the Savannah River Site, Dr. McCann conducted an extensive comparative evaluation of the EPRI and LLNL seismic Hazard assessments. This study, which involved extensive modification of the EPRI and LLNL seismic hazard software identified the source of the differences between the two studies and developed a single, composite estimate of the site hazard.

Dr. McCann recently assisted EPRI in developing an industry position regarding the seismic design basis for future nuclear power plants. As part of this effort, Dr. McCann is working with industry representatives and the USNRC to develop an effective, stable approach for seismic siting.

Dr. McCann was the project manager of a program to conduct an independent review of the EPRI seismic hazard software package, EQHAZARD. Following completion of the software review, JBA maintains the codes for EPRI according to Quality Assurance Standards.

Dr. McCann participated in a project to develop a USNRC external event PRA procedures guide and a review document for seismic and external flood hazards.

Department of Civil Engineering, Stanford University (since 1981) - Consulting Professor

Currently, Dr. McCann is the chairman of the National Performance of Dams Program (NPDP) Executive Committee. The NPDP is headquartered at Stanford. The program operates and maintains a library and database on dam incidents. The library contains over 6,000 documents, including the U.S. Committee on Large Dams incident files. The library and database will serve as a valuable resource for engineers to evaluate dam operating experience.

Working with the Association of State Dam Safety Officials, Dr. McCann was a chairman of a committee to develop a national standard for reporting the performance of dams. The result of this work was the publication of the Guidelines for Reporting the Performance of Dams.

Dr. McCann was the director of a project to develop probabilistic risk analysis procedures for the evaluation of dams. The project was supported under a contract with the Federal Emergency Management Agency (FEMA). The objectives of the project included the development of a probabilistic screening procedure to assign priorities to dams in a jurisdiction based on a cost-effectiveness criteria. A methodology to conduct a detailed probabilistic risk analysis of existing dams due to all stimuli was also developed.

Professional Activities

Member, Association of State Dam Safety Officials (ASDSO) Affiliate Member Advisory Committee

Member, American Nuclear Society - ANS-2 Site Evaluation

Chairman, American Nuclear Society ANS-2.29 Subcommittee - Probabilistic Analysis of Natural Phenomena Hazards for Nuclear Materials Facilities

Member of the American Society of Civil Engineers, American Geophysical Union, U.S. Committee on Large Dams, Earthquake Engineering Research Institute, and the Seismological Society of America

Awards

1989 Villanova University, John A. Gallen Award For Engineering Excellence

1994 Engineering News Record - Newsmaker

1995 Association of State Dam Safety Officials - President's Award

8. Work by firm or joint venture members which best illustrates current qualifications relevant to this project (list not more than 10 projects).

Jack R. Benjamin & Associates, Inc.
Consulting Engineers

a. Project Name & Location	b. Nature of Firm's Responsibility	c. Project Owner's Name & Address	d. Completion Date (Actual or Estimated)	e. Estimated Cost (in Thousands) Entire Project	Work for which Firm was/is Responsible
Seven Mile Dam Deficiency Investigation		**British Columbia Hydro and Power Authority 6911 Southpoint Drive Burnaby, British Columbia**	**1997**	**50**	**50**

Jack R. Benjamin & Associates, Inc. was retained by Klohn-Crippen, Ltd., a consultant to B.C. Hydro, to assist in the development and application of a risk-based methodology for a probabilistic risk assessment being performed for Seven Mile Dam.

As part of this project, JBA is providing the following services:

- reviewed the project work plan for selected tasks,
- provided consultation on probabilisitc model development ,
- review of probabilistic model developments, and
- technical report review.

Dr. McCann of JBA presented a three day course on methods to for conducting a probabilistic seismic analysis for structures and equipment. The purpose of this course was to provide hands-on training for engineers involved in the risk assessment project.

Specific areas where JBA engineers have provided input to the risk assessment to date include:

- identification of the importance of seismic events in the overall risk assessment,
- development of logic models to evaluate system performance during flood and non-flood events,
- evaluation and assessment of epistemic uncertainties, and
- review of the project scope of work for the risk quantification assessment.

As the project proceeds Dr. McCann will support the seismic part of the assessment, the risk quantification, and review of project reports.

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8. Work by firm or joint venture members which best illustrates current qualifications relevant to this project (list not more than 10 projects).

Jack R. Benjamin & Associates, Inc.
Consulting Engineers

a. Project Name & Location	b. Nature of Firm's Responsibility	c. Project Owner's Name & Address	d. Completion Date (Actual or Estimated)	e. Estimated Cost (in Thousands) Entire Project	Work for which Firm was/is Responsible
Probabilistic Flood Hazard Assessment for the N Reactor, Hanford, Washington		**U.S. Department of Energy Richland, Washington**	**1988**	**55**	**55**

Jack R. Benjamin & Associates, Inc. was retained by Lawrence Livermore National Laboratory to assess the frequency of flooding at the Department of Energy's N Reactor site which is located on the banks of the Columbia River. This probabilistic assessment considered the flooding that would occur due to extreme hydrologic events and the potential for flooding due to upstream dam failure. There are a total of 72 dams located upstream of the N Reactor site. In most cases failure of an upstream dam did not pose a flood hazard to the N Reactor. To evaluate the potential for flooding, a systems model was developed to determine the combination of events that could lead to flooding. The model considered the different initiators that could lead to dam failure (e.g., flood, seismic events, static failures), reservoir level, dam breach characteristics, dam operations and the response of a dam to overtopping. Event tree techniques were used to develop the system model (see the accompanying figure). As part of the flood hazard assessment, an estimate of the epistemic uncertainty was made. This included the uncertainties associated with parameter estimates, stage-discharge relationship, dam failure freqency estimates, etc.

In order to evaluate the flooding at the N Reactor site, dam break evaluations were conducted. This included the first assessments of the flooding that would occur in the U.S. in the event of a failure of Mica Dam.

8. Work by firm or joint venture members which best illustrates current qualifications relevant to this project (list not more than 10 projects).

Jack R. Benjamin & Associates, Inc.
Consulting Engineers

a. Project Name & Location	b. Nature of Firm's Responsibility	c. Project Owner's Name & Address	d. Completion Date (Actual or Estimated)	e. Estimated Cost (in Thousands) Entire Project	Work for which Firm was/is Responsible
Probabilistic Seismic Risk Assessment for the Savannah River Site Reactors; Seismic Hazard Evaluation - Seismic Structure/ Equipment Evaluation & Walkdowns, Risk Quantification		**Westinghouse Savannah River Company Continental Drive Aiken, South Carolina**	**1994**	**1,200**	**1,200**

As the operator for the Department of Energy's facilities at the Savannah River Site in South Carolina, Westinghouse performed extensive safety evaluations for the production reactors. As part of this project, JBA was responsible for:

1. probabilistic seismic hazards assessment for the SRS
2. seismic fragility evaluation for structures and equipment items
3. supporting the development of seismic systems models
4. quantification of the seismic risk of reactor accidents
5. presentation of results to review and oversight committees

The frequency of occurrence of earthquake ground motions at the SRS was determined using the results of the Electric Power Research Institute seismic hazard methodology. This assessment included the epistemic uncertainty in the site hazard estimate.

The seismic evaluations performed for the SRS reactors involved the most extensive assessment of Department of Energy weapons facilities to date. In particular, comprehensive seismic walkdowns and structural evaluations of the seismic response of structures and equipment were performed. As part of the seismic fragility assessment, screening procedures were used to identify the components that were vulnerable. Items determined to be robust, were screened and the basis for this determination were documented. For vulnerable components, failure modes were identified and seismic capacity and response evaluations performed. These results were then used to determine the seismic fragility, conditional probability of failure as a function of ground motion level, for each component.

Using software developed by JBA, we were responsible for the quantification of the frequency of seismically initiated reactor accidents. This involved the probabilistic combination of the site hazard, the fragility data for structures and equipment items and the system logic models (e.g., event trees and fault trees).

8. Work by firm or joint venture members which best illustrates current qualifications relevant to this project (list not more than 10 projects).

Jack R. Benjamin & Associates, Inc.
Consulting Engineers

a. Project Name & Location	b. Nature of Firm's Responsibility	c. Project Owner's Name & Address	d. Completion Date (Actual or Estimated)	e. Estimated Cost (in Thousands) Entire Project	Work for which Firm was/is Responsible
Probabilistic Risk Assessment for Locks and Dams on the Upper Ohio River		**U.S. Army Corps of Engineers Pittsburgh Pittsburgh, PA**	**1986**	**98**	**98**

As part of a planning study for the Upper Ohio River navigation system, a risk assessment was performed to evaluate the reliability of lock and dam systems. The study was performed for a 25 year period. One of the objectives of the study was to assess the long-term reliability of the lock and dam systems to service the expected increase in traffic on the upper Ohio River, accounting for navigation accidents, and potential structural failures. Of critical importance was the potential for the continued deterioration of concrete structures. Elements of the study included:

1. probabilistic seismic hazards assessment (i.e., seismic, flood events)
2. estimation of concrete deterioration
3. analysis of navigation accident data
4. probabilistic evaluation of structures and equipment items
5. site walkdown and evaluation
6. systems model development
7. risk quantification

The probabilistic risk assessment was performed for three lock and dam systems, Emsworth, Mongomery and Dashields.

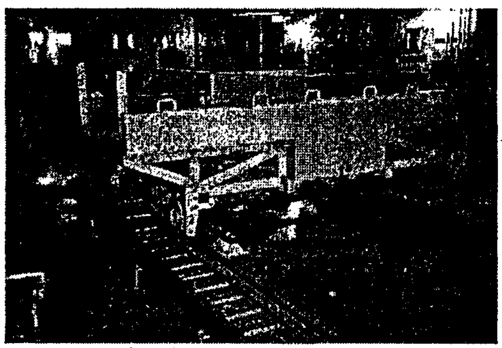
8. Work by firm or joint venture members which best illustrates current qualifications relevant to this project (list not more than 10 projects).

Jack R. Benjamin & Associates, Inc.
Consulting Engineers

a. Project Name & Location	b. Nature of Firm's Responsibility	c. Project Owner's Name & Address	d. Completion Date (Actual or Estimated)	e. Estimated Cost (in Thousands)	
				Entire Project	Work for which Firm was/is Responsible
Tooele Chemical Demilitarization Facility Seismic Safety Assessment Tooele, UT		**SAIC (Prime Contractor to the U.S. Army) 1309 Continental Drive, Suite F Abingdon, MD 21009**	**1995**	**530**	**464**

Jack R. Benjamin & Associates performed a probabilistic seismic hazard assessment, seismic walkdowns of site structures and equipment, structural screening and evaluation for seismic events, and resulting fragility analysis for the Tooele Chemical Demilitarization Facility for the U.S. Army.

The Army maintains inventories of chemical ordinance at a number of depots across the country. At the direction of Congress and the President, the Army developed a technology for the destruction of these inventories.



Demilitarization Equipment Analyzed by JBA for Seismic Ruggedness

A safety analysis conducted early in the project determined that the construction of weapon demilitarization facilities at the existing ordinance depots provided a more preferred alternative to the construction of a single centralized facility and the transportation of the ordinance. This decision prompted the development of plans for construction of multiple facilities, each subject to site specific environmental hazards.

The project consisted of an overall seismic safety assessment for a new facility to dismantle and destroy chemical weapons stored at the Tooele Depot. The JBA team provided the site seismic hazard profile using a probabilistic technique patterned after that developed by the Electric Power Research Institute for nuclear power sites. JBA conducted a site walkdown of an existing facility identical in design to the proposed Tooele complex, determining system, structure and component seismic fragilities considering item ruggedness and spatial interaction.

The seismic walkdowns implemented the state-of-the-art methodology for the critical review of seismic vulnerabilities and the numerical determination of seismic fragilities. JBA applied a screening approach much like the Electric Power Research Institute seismic margins methodology and the screening guidelines developed by the ICSSC for implementation of Executive Order 12491.

JBA demonstrated the applicability of its seismic screening and analysis experience gained in the examination of nuclear facilities to U.S. Government facilities subject to the requirements of Executive Order 12941. The Tooele project validated the use of prevailing nuclear industry methodologies to Government installations.

9. All work by firms or joint-venture members currently being performed directly for Federal agencies

a. Project Name & Location	b. Nature of Firm's Responsibility	c. Agency (Responsible Office) Name and Address and Project Manager's Name & Phone Number	d. Percent Complete	e. Estimated Cost (In Thousands) Entire Project	e. Estimated Cost (In Thousands) Work For Which Firm Is Responsible
JBA has no current government contracts at this time.					

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10. Use this space to provide any additional information or description of resources (including any computer design capabilities supporting your firm's qualifications for the proposed project.

JBA Probabilistic Risk and Decision Assessment Experience

Since its founding in 1979, JBA has been involved extensively in the application of probabilistic methods to civil engineer problems. In many cases, these projects were some of the early, **practical** uses of probabilistic approaches. In the past seventeen years, the use of probabilistic risk assess-ment and reliability methods has steadily increased. For example, in the early 1980's the use of risk assessment methods to evaluate the performance of nuclear power stations was just getting underway. Since that time, risk assess-ments have been performed for nearly all of the plants in the U.S., including the performance of civil, mechanical and electrical systems during seismic, wind and flood events. As pressures to design, build and maintain cost effective civil infrastructures increases, the use of risk-based methods to facilitate decision making is gaining wider acceptance.

JBA has been involved in the use of risk-based methods for a wide range of applications, including:

- evaluation of facility likelihood of failure,
- risk-based decision analysis,
- development of performance-based design criteria,
- systems analysis,
- determination of facility design basis events,
- screening/prioritization methods,
- identification of dominant failure modes and effects, and
- development of maintenance strategies.

At JBA we continue to look for improved, practical applications of risk-based methods to meet our clients needs.

Facility Risk Assessment
JBA engineers have performed risk or reliability evaluations for a wide range of civil systems. The purpose of these studies is to determine the critical modes of failure (typically functional rather than structural failure is assessed) and their likelihood of occurrence. The insights from these evaluations are used in a variety of ways, including the identification of modifications to improve system reliability and support regulatory reviews or petitions.

The types of facilities that JBA engineers have performed risk assessments for, include:

- dams
- lock and dam systems
- levees
- pipelines
- nuclear power plant structures and equipment items
- weapons storage igloos
- chemical weapons demilitarization facilities
- fuel and water storage tanks
- fuel storage racks
- commercial and residential construction

Like other engineering tools, risk-based methods can be performed at a number of levels. Their use can be tailored to the problem and resources available. As an analogy, in structural engineering a detailed finite element analysis is performed when the complexity of the problem and the available resources warrant its use. Otherwise a simple calculation is performed to meet the project needs. At JBA our experience in the use of risk-based methods allows us to **tailor** the analysis to meet a project's requirements.

Levee Reliability Assessment
As an indication of JBA's leading edge experience, we performed on of the early risk-based evaluations for levee systems. As part of a National Science Foundation sponsored study, JBA engineers under the direction of Dr. Benjamin, developed an approach for evaluating the likelihood of failure of levee systems. The methodology considered levee performance during seismic, flood and static events. The methodology was then applied to a levee system in the Sacramento Delta area.

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10. Use this space to provide any additional information or description of resources (including any computer design capabilities supporting your firm's qualifications for the proposed project.

Development of Design Standards

One of the important applications of risk assessment methods is the development of consistent design requirements. JBA engineers have used risk-based methods to establish design criteria for civil structures for seismic, wind and flood loads. These applications have focused on the development of design basis loads and evaluation methods to satisfy specific performance criteria. For example, as part of the U.S. Department of Energy's effort to develop consistent design criteria for natural phenomena (e.g., seismic, wind and flood hazards), a probabilistic approach was taken. Dr. McCann of JBA was responsible for the development of the flood hazard design basis events and evaluation criteria.

Screening/Prioritizing Methods

One of the practical applications of risk-based methods is in the development of consistent methods to screen or rank events. These approaches can be a cost effective means to focus resources in a project. As part of his work at Stanford, Dr. McCann developed a screening approach for dam safety modifications. In another application, JBA engineers have used risk-based concepts to develop screening tools when performing risk evaluations for complex facilities (e.g., nuclear power stations). The benefit of these screening tools is realized when the number of structures and equipment items that must be analyzed in detail is reduced from a relatively large number (e.g., 100-200 items), to a much smaller, more manageable number (e.g., 10-50 items).

Evaluating Uncertainties

One of the important parts of a risk-based assessment is the identification and quantification of uncertainties. There are two fundamentally different sources of uncertainty that effect the assessment of the likelihood of future events. The first source of uncertainty is attributed to the inherent randomness of events in nature (e.g., the toss of a coin, the occurrence of earthquakes in time and space). These events can only be predicted in terms of their likelihood of occurring. This source of uncertainty is known as **aleatory uncertainty**, and is irreducible.

The second type of uncertainty is attributed to lack of knowledge or data. For example, the ability to determine the likelihood of an event (i.e., its rate of occurrence), requires that certain data be available. If the amount of data is adequate, the estimate of a rate of occurrence will be accurate. On the other hand, if only limited data is available, an estimate of the rate will be uncertain (i.e., statistical confidence intervals will be large). Another source of knowledge uncertainty is attributed to professional judgement/experience of the engineer(s) who must model a physical process or system. For example, in conducting a hydraulic assessment, the analyst may know that the calculations that he/she is performing cannot exactly model the physical process being analyzed (even with good input). As a result, there is a model uncertainty that exists. These sources of uncertainty are referred to as **epistemic uncertainty**. In principle, epistemic uncertainties are reducible with the collection of additional data or the use/development of improved models. In a given project, however, it is not always possible to reduce these uncertainties.

In a risk-based assessment it is important that both sources of uncertainty be identified and quantified to the degree possible. Dr. McCann of JBA was recently involved in a project where methods for addressing epistemic uncertainties were developed.

The assessment of epistemic uncertainties can be critical. Their formal assessment requires a certain level of evaluation that adds defensibility and completeness to a project. From a quantitative perspective, the assessment of epistemic uncertainties provides a best estimate of the desired result and the equivalent of confidence intervals. The final confidence intervals are an aggregation of the different sources of epistemic uncertainties, which includes alternative models, uncertainties due to limited data, and alternative professional judgements.

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10. Use this space to provide any additional information or description of resources (including any computer design capabilities supporting your firm's qualifications for the proposed project.

JBA Risk and Hazard Assessment Software Tools

As part of our project experience, JBA engineers have developed software tools or modified existing programs to perform computations required as part of probabilistic risk and hazard assessment computations. These software packages include:

- FL_HAZ - Probabilistic flood hazard assessment (developed by JBA)
- JBALIFE - Lifeline risk assessments
- SHIP - Systems based risk quantification software (developed by JBA)
- JBA_HAZ - Seismic hazard assessment software

A summary of these codes is provided below.

FL_HAZ - This software package was developed by JBA to perform comprehensive flood hazard calculations. The purpose of this software package is estimate the frequency of exceedance of flood stage levels at a site. The accompanying figure shows the basic steps in the assessment.

The code was specifically designed to take into the epistemic (knowledge-based) and aleatory (random, inherent) uncertainty in flood hazard assessments. Sources of epistemic uncertainty include the uncertainty associated with the length of the historic record and choice of the flood frequency model. These uncertainties can be modeled in FL_HAZ to develop a composite estimate of the frequency of flooding.

For a given data set, the FL_HAZ can evaluate multiple flood frequency relationships (e.g., Log-Pearson, Extreme Value, Pearson) and incorporate these in a composite estimate of the frequency of flood discharge. The results of the flood discharge frequency analysis (which may include multiple models) is combined with a probabilistic stage-discharge model that accounts for the epistemic and aleatory uncertainty in stage. The result of this software is a series of flood stage hazard curves that quantify the frequency of exceedance of flood discharge and stage as well as the uncertainty in these frequency estimates.

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10. Use this space to provide any additional information or description of resources (including any computer design capabilities supporting your firm's qualifications for the proposed project.

JBA Risk and Hazard Assessment Software Tools (cont.)

JBA_LIFE - To evaluate the performance of spatially distributed systems (e.g., water supply systems), JBA engineers modified existing an existing program developed at MIT to produce JBA_LIFE. It includes the capability to model the functional logic of a lifeline system (e.g., network logic that defines the system operation) and the spatial variation of a hazard (e.g., earthquake ground motion, flooding) to evaluate the system reliability. A system can be defined in terms of components that are spatially distributed (e.g., a levee system, pipeline) or located at a point (e.g., a pump station). The reliability of components in the system can be defined in terms of a rate of failure (e.g., rate per length) or a in terms of a probability distribution.

The code solves the system logic to determine the probability of failure of the system to survive specific event. JBA_LIFE can also be used to evaluate the annual frequency of system failure for the range of future random events that can occur (e.g., flooding of different magnitudes, seismic events).

Seismic Hazard Software - JBA has two primary codes available to perform probabilistic seismic hazard assessments. We are a licensed user of the Electric Power Research Institute's seismic hazard software package, EQHAZARD. This package is generally applicable to sites located in intraplate regions such as the central and eastern U.S. For sites in the western U.S. and elsewhere, we have modified an existing code developed at Stanford University. This software package, JBA_HAZ, has the following capabilities:

- model seismic sources as three dimensional fault planes as well as line and area sources,
- suite of ground motion attenuation models to choose from,
- use a characteristic model to evaluate the frequency of earthquake occurrences,
- model the epistemic and aleatory sources of uncertainty, and
- generate deaggregated hazard results to easily evaluate the contribution of different seismic sources to the site hazard and different size earthquakes to the total hazard.

Recently, this software was used to evaluate the seismic hazard at a site in Japan where tectonics of the region were extremely complex.

10. Use this space to provide any additional information or description of resources (including any computer design capabilities supporting your firm's qualifications for the proposed project.

SHIP - SHIP was developed by JBA to perform probabilistic risk assessment calculations for civil infrastructure systems exposed to seismic, wind and flood external hazards. The program accepts as input:

- site hazard information (e.g., flood frequency curve, seismic ground motion hazard curve),
- component vulnerability data (e.g., fragility curves that define the conditional probability of failure as a function of the hazard level), and
- systems logic model (e.g., event tree and/or fault trees).

The purpose of SHIP is to use these inputs to assess the frequency of system failure and to provide the engineer with insights to the failure modes that are the dominant contributors to system failure. The accompanying figure shows the elements of a SHIP evaluation for seismic events.

Unique features of SHIP include:

- the capability to propagate epistemic and aleatory uncertainties for each part of the analysis to the final results,
- the capability to analyze system logic models (e.g., event and fault trees),
- an algorithm to solve system fault trees correctly, without making simplifying assumptions, and
- the ability solve seismic event trees, including success and failure events.

The program is designed to provide a wide range of intermediate and final results to support the engineer's efforts to understand the performance of a system. Products generated by SHIP include:

- fragility curves (curves that define the conditional probability of failure given the hazard level) for individual sub-systems as well as for the whole system,
- fraction contribution of each system failure mode to the total frequency of system failure,
- fraction contribution of different hazard levels (e.g., flood stage) to the frequency of system failure, and
- probability distribution (e.g., total epistemic uncertainty) on the frequency of system failure

The code has undergone a Quality Assurance review that meets the requirements of 10 CFR Part 50, Appendix B. JBA has sold SHIP to a number of electric utility clients.

10. Use this space to provide any additional information or description of resources (including any computer design capabilities supporting your firm's qualifications for the proposed project.

Past Performance
In support of our ability to meet anticipated project requirements, the following references are provided:

Dr. Bryce Johnson
Science Applications International Corporation
5150 El Camino Real, Los Altos, CA 94022
(415) 960-5936

Elwyn Wingo
Westinghouse Savannah River Co.
Aiken, South Carolina 29803
(803) 279-2257

Malcolm Barker
Klohn-Crippen
610 Burrard Street, Vancouver, British Columbia
(604) 664-2076

Mark Brandyberry
Science Applications International Corporation
1309 Continental Dr., Suite F
Abingdon, MD21009
(410) 679-8262

Frank Stanaszak
Wisconsin Public Service Corpn.
Green Bay, WI 54307-9002
(414) 388-2560

Capacity To Accomplish Work
JBA staff members are available at least 50 percent time (including Dr. McCann) to work on Corps projects over the 12 month duration.

Quality Control
JBA maintains an active quality assurance program that meet the standards of 10CFR50, Appendix B. This experience demonstrates our familiarity with the need for and ability to implement quality assurance programs.

Team Location
JBA is located in the San Francisco Bay area, a two hour drive to downtown Sacramento. Due to our close proximity to the other team members, we are able to work with and meet as necessary other team members and Corps personnel.

DOD Work
In the last 5 years JBA has not worked under direct prime contract to the Department of Defense.

Small-Business
JBA is a small business with gross receipts of less than $2.5 million annually.

Project Organization
JBA tasks will be managed by Dr. McCann. In addition, he will be involved in all technical phases of Corps tasks.

11. The foregoing is a statement of facts.

Signature: MWMcC Typed Name and Title: Martin W. McCann, Jr., President

Date: February 27, 1997

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Appendix B

Will Betchart Background and Experience

WILL B. BETCHART, P. E.
Consulting Water Resources Engineer
17050 Montebello Road
Cupertino, CA 95014

Phone: (408) 741-5762 **Fax: (408) 252-1444**

Mr. Betchart is a California and Colorado Registered Civil Engineer with over 25 years experience in the water resources and environmental fields. He has performed and managed national, state, regional, and basin-wide planning for water resources, groundwater, and water quality; project-level planning, alternatives analysis, cost estimating, and impact assessment; feasibility studies; licensing/ permitting/ EIS/EIR studies; and conceptual design. Mr. Betchart's project-work emphasis is on problem definition, solution concept development and technical, economic and financial feasibility studies. He is expert at comprehensive analysis of integrated water and environmental planning issues. He is adept at quantitative analyses and modeling of such issues, definition of project objectives and criteria, and analysis of proposed actions relative to economic and other criteria for decision making. He has particular skill in comprehensive review, technical and quantitative assessment and issue resolution in the complex institutional setting associated with water resources, water quality, and environmental issues. Mr. Betchart is experienced at presenting technical material to clients and within integrated planning processes and community relations/ public participation programs. He has been responsible for developing, scoping and managing such planning processes. His masters degree and doctoral studies emphasized water quality and water resources management with minors in mathematics and economics.

Mr. Betchart's planning and design work has addressed pipelines, canals, pumping plants, water treatment plants, tunnels, dams, and hydropower. His experience includes technical leadership for portions of the Water Supply Management Program of East Bay MUD, which was their integrated resource plan developed within an EIS/EIR framework. He has developed plans of study, multi-facility project concepts; innovative conceptual designs; project layouts; project siting reconnaissance studies; hydrologic and hydraulic analyses; water quality and groundwater modeling; water conservation and reclamation studies; surface- and groundwater conjunctive use program development; community water supply programs; environmental data program designs; multi-phase development plans; constructibility assessments; and reliability assessments.

Representative project experience of Mr. Betchart includes :

- **East Bay Municipal Utility District, Updated Water Supply Management Program** -- Engineering screening studies, conceptual designs and planning/analyses in support of EBMUD (Oakland, CA) environmental impact (EIS/EIR) process to select a long-term water supply enhancement program. Responsibilities included task leadership in surface/groundwater conjunctive use site screening and project development and in surface reservoir site screening studies plus conceptual design of other alternatives, cost estimates, and groundwater, water quality, and sediment related impact assessment for short-listed alternatives.

  - Conjunctive Use Studies -- Mr. Betchart served as technical task leader for EIS/EIR program-level studies to identify/screen suitable areas for conjunctive use (including large potential for water storage in aquifers) and to develop alternative programs for possible inclusion in EBMUD's water supply plans. The Lower Mokelumne River area (in the vicinity of Lodi) was selected. The study demonstrated the potential for substantial contributions to EBMUD's water supply in a prolonged drought.

Three different conjunctive use program themes were developed: (a) saving surface water for EBMUD use in dry years by switching irrigators to ground water, (b) saving more surface water in dry years by using groundwater for part of the instream flow requirements, and (c) directly using groundwater in dry years for EBMUD water supply. Specific ground-water recharge and withdrawal locations and mechanisms were identified at various program magnitudes for each theme. Intensive groundwater pumping in a sequence of critically dry years was shown to provide a major supplement to surface supply safe yield. Aquifer recharge, storage and conjunctive use was selected as EBMUD's preferred alternative.

- Earthquake Safety Assessment of the Mokelmne Aqueduct San Joaquin Delta Crossing -- Prepared a "Summary of Findings" report on the seismic vulnerability of the aqueduct due to the Delta seismic environment and foundation conditions. The report drew on documentation of a detailed geotechnical investigation of seismic and foundation conditions with special attention to aqueduct levee crossings. A high probability of levee failures due to earthquakes within the next 30 years was noted (based on present understandings) together with significant uncertainties in technical data and relationships that require further study.

- Surface Storage Reservoir Site Screening -- Mr. Betchart served as technical task leader for potential dam/reservoir site identification, conceptual layout of inlet and outlet tunnel/pipeline systems, planning analysis, cost estimation and screening evaluations. Some 94 potential dam and reservoir sites in the San Francisco Bay Area and in the Central California Sierras were identified and evaluated for inclusion on a "short list" of preferred sites carried forward.

- Tunnel Routing Alternatives for Buckhorn Reservoir -- Identified/developed alternative tunnel conceptual designs to avoid major pipeline construction in downtown Moraga.

• **City of Roseville, Folsom Dam Pumping Plant** -- Managed/performed analysis of head losses and pumping capacity for Folsom Project water supply facilities at various reservoir water levels. Analyzed pumping test data to resolve flow measurement discrepancies. Developed conceptual designs, performance analyses and cost estimates to address wide variations in pumping head and demand. Recommended pumping plant expansion by adding two large variable speed pumps to increase capacity. Presently overseeing project design.

• **Sacramento Area Flood Control Agency, Auburn Bridge** -- Identified site for a high Auburn/Highway 49 bridge that allows for potential of future Auburn Dam raise after first phase flood control dam. Corps' proposed bridge is low and incompatible with raise. Developed conceptual design and cost estimate for high bridge and met with stakeholder agencies to work out traffic concerns. Found that acceptable high bridge can be built at approximately same cost as Corps' lower bridge.

- **Sacramento Area Flood Control Agency, Folsom Gate Failure** -- With hydraulic and structural experts, providing peer review services relative to forensic team analysis of Folsom Dam Gate No. 3 failure.

- **Sacramento Area Flood Control Agency, Folsom Dam Reliability** -- With a systems reliability expert, developed a technical approach, scope and budget for conducting a comprehensive reliability analysis of Folsom. The overall objective, as a follow on to the Gate No. 3 failure, would be identification of other vulnerabilities that may result in downstream flooding.

- **Sacramento Area Flood Control Agency, O & M Costs** -- For three alternative flood control plans, reviewed Corps estimates of annual operation, maintenance and replacement costs and suggested substantial revisions. Met with SAFCA and Corps representatives to develop consensus estimates.

- **Sacramento Area Flood Control Agency, Folsom Dam Improvements for Flood Control** -- Managed/performed conceptual design and technical feasibility/ reconnaissance studies of potential major modifications to Folsom Dam to enhance flood control (as an alternative to Auburn Dam). Constructibility, while respecting ongoing flood control, water supply, and hydroelectric uses is a major issue for this facility on the American River in California. Work included development of detailed conceptual designs and cost estimates for two main alternatives:

  - Dam Raise -- One improvement examined and found to be feasible is a 30-foot raise of the 350-foot high dam, adding 360,000 acre-feet to its existing 1,000,000 acre-foot reservoir. The dam consists of a 1400 foot long concrete gravity structure across the river channel, extended by embankment wing dams and supplemented by nine additional saddle dams totalling five miles in length. The project would require a challenging schedule to extend the concrete dam and restore adjacent embankments during one dry season. Overall project cost would be approximately $480 million.

  - High Capacity Discharge Tunnels -- A second improvement examined and also found to be feasible is adding low-level outlet capacity by using up to five large diameter bottom spillway outlet tunnels with upstream orifice controls and wheel gates and a combined capacity exceeding 100,000 cfs in order to quadruple discharge capability during early flood stages and save reservoir storage capacity for the flood peak. The tunnel project would cost approximately $150 million. Reuse of the existing (presently plugged) construction-period river diversion tunnel was also considered but found to be infeasible because of very high head and constructibility issues.

- **Santa Clara Valley Water District, Coyote Dam Outlet Works Replacement Project** -- Engineering design of a new intake structure, tunnel, outlet channel, and seepage monitoring facilities to replace the existing outlet threatened by siltation. Developed design criteria, civil specifications (including erosion control and other environmental controls and mitigations) and Engineer's cost estimate.

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- **Santa Clara Valley Water District, Maple and San Pedro Avenue Recharge Facilities** -- Research, analysis, and recommendations on recharge pond design in response to high lateral and low vertical permeabilities.

- **Stockton East Water District, Groundwater Recharge** -- Managed an evaluation of recharge pond feasibility for land areas adjacent to the Stockton East Water Treatment Plant based on data from subsurface exploration performed previously for treatment plant design and construction.

- **Stockton East Water District, Deer Creek Reconnaissance**-- Managed/performed conceptual design, technical feasibility study and cost estimate for Deer Creek Reservoir, a potential 600,000 to 800,000 acre-foot, off-stream flood control and water supply reservoir in the Sierra Nevada foothills (as a potential alternative to Auburn Dam). Work included diversion facilities and a 135,000 cfs RCC-lined canal to convey flood flows and a 20 MW pumping plant and conveyance canal for water supply storage and delivery.

- **Calaveras County Water District / Northern California Power Agency, North Fork Stanislaus River Hydroelectric Development Project** -- Mr. Betchart coordinated engineering/detailed design for the turnkey contractor's design team on the $270 million "Calaveras Project" which includes four dams (two over 240-feet high), seven tunnels (one 18 feet in diameter and 7.5 miles long), a vertical shaft (12 feet in diameter and 2200-feet deep), three penstocks (one with pressure greater than 1000 psi) and two powerhouses (five units totaling 257 MW). Responsibilities included writing or reviewing all specifications; managing the resolution of technical problems identified by Owner, Contractor, or Engineer's field representative; coordinating and reviewing design work; coordinating responses to FERC and dam safety agency questions and submittal requirements; managing employees and subcontractors; maintaining schedule; tracking budget; complying with contract scope and securing change orders for out-of-scope work; and being contact point for the Turnkey Contractor and project Owner.

- **County of Sacramento, Department of Environmental Review and Assessment, Draft EIR for Gravel Mining** -- For Aspen VI (Teichert) and Granite Rezoning and Use Permit application, Mr. Betchart provided EIR analysis of environmental setting, impacts, mitigation measures and project alternatives relative to surface and ground-water hydrology and water quality. One issue was flood attenuation impacts on Morrison Creek. Another issue involved TCE and PCE contaminant plumes affecting the proposed mining site, apparently originating from Mather Air Force Base. Impacts addressed included contamination of the gravel resource, contaminated washwater and fines from gravel washing, and health and safety of mine workers.

- **U.S. Environmental Protection Agency, Report to Congress on Water Supply and Wastewater Treatment Coordination** -- Performed technical studies as part of report development on nation-wide water use, ground-water contamination, ground-water overdraft, conjunctive use, wastewater reclamation, water conservation, and small system technology and operation/management needs. The groundwater contamination issue emphasized assessment needs for sites that are potential sources of contaminant plumes. Required consideration of EPA's coordination needs with other laws including RCRA, TSCA, and FIFRA. The report was used to draft revisions to the Clean Water Act and the Safe Drinking Water Act.

- **U.S. Environmental Protection Agency, "Wastewater Flow Reduction Handbook"** -- As project manager, developed a guide book to identify technical alternatives and economic analysis procedures for building water conservation programs in urban areas. EPA interest was in reducing wastewater flows, but analysis procedures included water supply and energy savings as well. Three case studies were performed (Carbondale, Illinois; Tucson, Arizona and Manteca, California).

- **U.S. Army Corps of Engineers, San Francisco District, Klamath River Basin Plan of Study** -- Performed reconnaissance level planning for Klamath River Basin, Oregon addressing Upper Klamath Lake eutrophication, water quality in Lake Ewauna and the Klamath River, hydropower development on the Klamath River, fish and wildlife, recreation and water supply for agriculture, hydropower, and fisheries.

- **U.S. Army Corps of Engineers, Alaska District, Anchorage Water Resources Plan of Study** -- Prepared detailed plan of study for Corps urban water resources study in Anchorage, Alaska. Issues included issues of urban runoff quality, wastewater disposal/dispersion, and municipal water supply.

- **Upper Mississippi River Basin Commission, Twin Cities Water Plan** -- In Minneapolis-Saint Paul, conducted multi-disciplinary, interagency workshops to apply Water Resource Council's Level B issue-oriented planning guidelines to wastewater disposal, non-point source controls for lakes, water supply, flood control, navigation and recreation problems.

- **Hawaii Department of Natural Resources, Hawaii Water Plan** -- Worked with state and local agency personnel in Hawaii to apply Water Resource Council's Level B issue-focused water planning guidelines. Addressed irrigation efficiency, groundwater quality, basal lens protection and safe yield and non-point source pollution (primarily sedimentation) impacts on coral.

Employment Summary

1990-1996	**ESA Consultants Inc. / Earth Sciences Associates** Water Resources Engineer and Associate
1985-1990	**Calpine Corporation / Electrowatt / Sandwell, Inc.** Project Engineer, Senior Water Resources Engineer
1982-1985	**Gibbs & Hill, Inc.** Project Engineer
1975-1982	**INTASA, Inc.** Senior Water Resources Engineer

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	1974-1975	**Water Resources Engineers** Associate Water Resources Engineer
	1973-1974	**University of Washington, Department of Civil Engineering** Research Assistant Professor
	1968-1973	**University of Illinois, Urbana-Champaign Campus, Institute for Environmental Studies and Water Resources Center** Assistant Research Engineer

Education

B.S., Civil Engineering, University of Colorado, Boulder, 1966
M.S., Civil Engineering (Water Resources/Environmental), University of Colorado, Boulder, 1967
Doctoral Studies, Civil Engineering, University of Illinois, Urbana-Champaign Campus, 1968-1972

Registrations

Registered Professional Engineer (Civil), California, 1981
Registered Professional Engineer, Colorado, 1975

Professional Affiliations

American Society of Civil Engineers
American Geophysical Union
American Water Resources Association
American Water Works Association
Association of Ground Water Scientists and Engineers (AGWSE) (formerly National Water Well Association)
Groundwater Resources Association of California
U.S. Committee on Large Dams
Water Environment Federation

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